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Provisional Specification

for an invention entitled:

METHODS AND SYSTEMS (NPW009)

The invention is described in the following statement: -

METHODS AND SYSTEMS (NPW009)

Digital Ink Line Orientation Estimation

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1 Introduction

Digital ink processing systems must deal with the huge variability in handwriting and drawing that occurs due to the differing styles of individual writers. As a result, most systems perform a number of pre-processing steps to limit this variation. Examples of such systems include handwriting recognition systems, digital signature verification systems, document analysis systems, and digital ink searching systems.

A commonly used instance of such a procedure is orientation normalization, which is used to reduce the variance of the input by aligning the digital ink as if it was written using a standard orientation on the page (for example, written left-to-right on a horizontal line for Latin character based scripts). By aligning the digital ink in such a way, the ink processing system can ignore the effects of variation in orientation, and as such can be made simpler, more robust, and more accurate.

Orientation normalization is usually performed as one of the first steps in a digital ink processing system, and is used to minimize error in later stages (for example, line, word, and character segmentation, feature extraction, etc.) Generally, the angle of a segment of digital ink relative to a standard reference angle (e.g. horizontal) is estimated and used to re-orient the digital ink such that the angle of digital ink matches the reference angle.

Orientation normalization for Latin character scripts is often performed using baseline correction, where the baseline of a line of text is defined as the imaginary natural line on which a user places characters that do not have descenders (e.g. "a", "b", "c", "d", "e", "f", "h", etc.). This is done by estimating the baseline of a segment of digital ink and then rotating the ink to be horizontal. Whilst most systems assume baselines are roughly linear, some systems attempt to model baseline drift using more sophisticated models such as splines [12].

In this paper, a novel method for estimating the orientation of a segment of digital ink using pen orientation information is described. The technique involves using training data to build a pen orientation model for an individual writer, which is used to estimate the orientation of subsequently written digital ink.

1.1 Prior Work

A significant amount of research has been performed on orientation estimation and normalization for digital ink, with particular emphasis on techniques that are applicable to Optical Character Recognition systems. Early research systems relied on heuristics and empirical thresholds [4,5], along with simple techniques such as linear regression through stroke minima [1]. Due to the brittle nature of these techniques, more sophisticated systems using projection profiles [2,9] and generalized projections [3] were developed. Many other techniques have since been developed, including: least squares and weighted least-squares [7,18], geometric modelling and pseudo-convex hull [6], techniques based on the Hough

transform [8], model based methods [10], skew detection using Principal Component Analysis [11], and baseline estimation using approximating spline functions [12].

A number of orientation normalization techniques have been patented, including the use of boundary projections combined with the Hough transform [13], a system for digit normalization of scanned images that works by finding the bounds of a parallelogram that completely encloses the character image [14], methods that use linear projection and a clustering algorithm to detect elements in a histogram that correspond to ascender, descender, and base lines [15,16], and a least squares calculation combined with rotation around a centroid for the normalization of signatures [17] in an online signature verification system.

Whilst the techniques described above are often effective, most suffer from a number of significant limitations. For example, many assume that all lines of written text are oriented at the same angle on the page, and thus cannot handle pages of arbitrarily rotated text lines. Other limitations include the fact that the algorithms require significant processing resources (e.g. Hough transform), are quantised (e.g. Hough transform), do not work well for short segments of text (e.g. projection methods), are brittle due to empirically estimated thresholds (heuristic and rule-based techniques), or are sensitive to ascenders, descenders and outliers (e.g. least squares regression and projection techniques).

The digital ink orientation estimation technique described in this paper is not subject to the limitations described above, and improves on current techniques by utilizing pen orientation information that has been previously unavailable or ignored by other systems. In addition to this it uses training data to generate a writer-dependent pen orientation model that is used during orientation estimation.

2 Orientation Estimation

This section describes the use of azimuth measurements to perform orientation estimation for written digital ink. A definition for azimuth is given, along with measurements of pen azimuth for a number of writers. The generation of a writer-dependent model and subsequent use for orientation estimation is described, with an example given for illustration. Finally, a number of orientation normalization techniques for use with the orientation estimate are discussed.

2.1 Azimuth

The azimuth of a writing implement is defined in [19] as the "clockwise rotation of the cursor about the z axis through a full circular range". In other words, if x and y define the horizontal and vertical axes of a sheet of paper, and z defines the axis that is normal to the paper, azimuth is the rotation of the pen about the z axis. Many pen-based computing systems are able to measure the azimuth of a writing implement during the generation of digital ink, including Wacom graphics tablets and Netpage pens [20].

2.2 Azimuth Measurements

A digitising tablet was used to measure the azimuth of a pen during the generation of handwriting by five different writers. Digital ink was collected using a Wacom Intuos graphics tablet with a sampling rate of 100 Hz. The data collection application was developed using the Wintab Programmer Development Kit Version 1.26 [19].

Table 1 details the azimuth measurements for the sample data collected, where the angles are measured clockwise with 0° representing a vertical line pointing to the top of the page. Note that the azimuth measurements reveal that writer 2 is left-handed. Table 2 details the average, minimum, maximum, and standard deviation of the azimuth measurements for the sample data for both left- and right-handed writers, with this data displayed in Figure 1.

Table 1. Average, minimum, and maximum azimuth measurements.

	Handedness	*Average*	*Minimum*	*Maximum*
Writer 1	Right	130°	109°	148°
Writer 2	Left	294°	275°	316°
Writer 3	Right	149°	124°	173°
Writer 4	Right	141°	123°	157°
Writer 5	Right	133°	119°	159°

Table 2. Average, standard deviation, minmum and maximum measurements

Handedness	*Average*	*Std. Deviation*	*Minimum*	*Maximum*
Right	138°	11.9°	109°	173°
Left	294°	8.2°	275°	316°

It is obvious from the results that the azimuth of a pen during handwriting is stable for a particular writer (as can be seen by the small standard deviation and difference in the minimum and maximum values).

2.3 Orientation Estimation

To estimate the orientation of digital ink using the azimuth measurements, the system needs a handwriting model to be available. Whilst the technique works with a small number of writer-independent models (e.g. one for left-handed writers and another for right-handed writers) that do not require training, the most accurate results are achieved using a writer-dependent model that is trained using sample input from the writer. To do this, the system is trained using digital ink data that was written using a consistent, well-defined baseline. This data can be derived from normal input (for example, form input data that is constrained to be written horizontally) or from a separate training procedure. The training data is then used to generate a model for the writer as shown in Figure 2.

Alternatively, the system can be trained using arbitrary handwritten input (i.e. without explicit training data) by using an alternative orientation estimation technique to truth the data from which the writer-dependent model is generated. Since the training data does not need to be large (a few letters can be sufficient), the technique used to truth the data can be very expensive since it is only run once on a small segment of ink. In addition to this, algorithms that fail in some situations can be used, since a single successful orientation estimation is all that is required for the training procedure.

Once the model has been generated, it can be used for line segmentation and orientation estimation and normalization. When performing line segmentation, a large jump in the azimuth value (e.g. a value larger than the expected variance as given by the writer-specific model) is an indication of the start of a new line of text with an orientation different from that of the previous line. For orientation normalization, the model can be used to generate an estimate of the text orientation for the line segment, which is then used to perform baseline normalization.

As an example, Figure 3 depicts the measured azimuth vectors for a stream of digital ink handwriting. The vectors represent the orientation of the pen during the generation of the ink, and the angle of the pen relative to the page can be seen to change smoothly during the writing. To estimate the orientation of the digital ink in this example, a simple mean azimuth model was used, where the mean of the azimuth values in a set of training data (a single horizontal line of text written by the same writer) was calculated and stored:

$$\overline{a} = \frac{\sum_{i=1}^{n} a_i}{n}$$

(1)

where a_i is the azimuth measurement in degrees at sample i, and n is the number of samples in the digital ink.

The mean value represents the normal azimuth that the writer holds the pen relative to the page when writing. To estimate the orientation at each sample point, the mean values was subtracted from the azimuth values of the digital ink example shown in Figure 3, with the results normalized to ensure they are in the range 0° – 360°:

$$a_i = \begin{cases} a_i - \overline{a} + 360° & a_i - \overline{a} \leq 0° \\ a_i - \overline{a} & otherwise \end{cases}$$

(2)

where a_i is the azimuth measurement in degrees at sample i, and $\overline{a}$ is the mean azimuth value for the writer (as calculated previously).

The mean azimuth value derived from the training data was approximately 130°. This value was subtracted from each of the measured azimuth values show in Figure 3 giving the normalized orientation estimates are shown in Figure 4. As can be seen, the estimated vectors give a good indication of the baseline orientation for the text at each point on the digital ink path. These orientation vectors can then be used for orientation normalization.

Once the ink orientation has been estimated, a number of orientation normalization techniques are possible. A simple method for text written with a linear baseline is to find the mean estimated orientation of the samples in the digital ink segment, and rotate the ink to counter this orientation. More sophisticated techniques include using a smoothed running estimate of the orientation, or fitting a curve (e.g. spline) to the estimated orientation vectors and warping the digital ink segment to ensure the estimated baseline is horizontal and linear.

3 Conclusion

A novel technique for estimating the orientation of digital ink using the azimuth of the writing device is given and the use of this measurement to perform orientation normalization line segmentation is discussed. In addition to this, the azimuth measurements of a number of different writers is given and analysed.

4 Figures

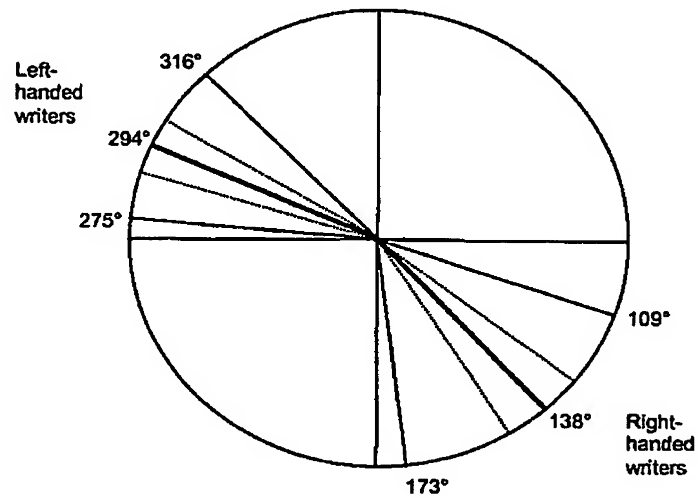

Figure 1. Average (bold), minimum, maximum, and standard deviation (dotted) azimuth measurements for left- and right-handed writing.

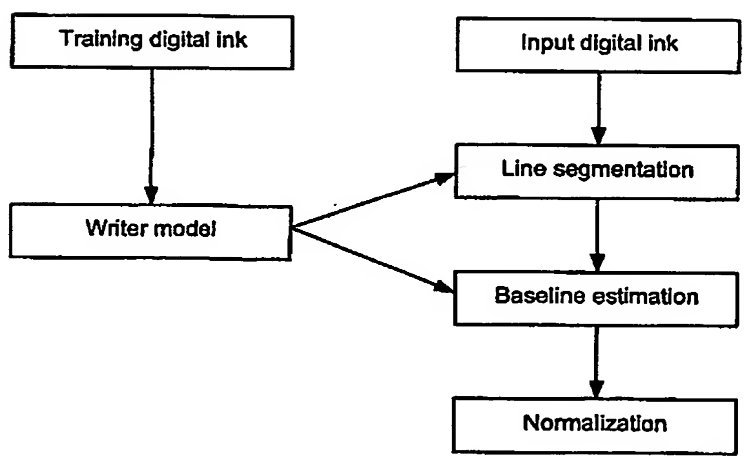

Figure 2. Training and normalization procedure

Figure 3. Azimuth vectors

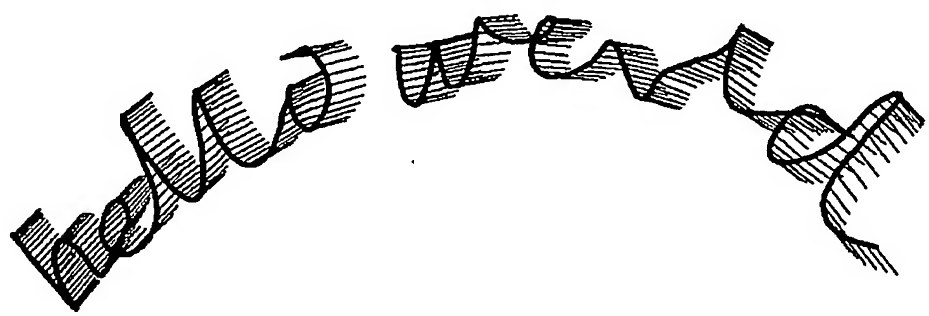

Figure 4. Orientation estimation vectors

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